Feasibility study of Mg Scrap Hydrolysis for hydrogen generation using HCl by energy cost analysis

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***Abstract*— Due to the importance of energy and the tendency to find a renewable source of energy, the energy field has been linked to all studies areas to find the optimal methods for the energy production. The concern about environmental pollution and the needs of human for the clean energy supply have attracted researchers' attention to search about new technology to utilize the solids waste from the electronic and automobiles industries in such a way to produce energy which can be advantageous in two ways; this can manage the solid waste and produce source of energy. In this study, Mg scraps have been used for the hydrogen generation via hydrolysis. The total energy cost has been calculated to predict the performance of the process depending on the cost of chemicals that have been used to generate H_2 gas. Hydrolysis process was conducted with different concentrations of HCl to study the effect on the hydrogen gas generation using Mg scraps. This work optimizes the process of using Mg scraps to produce H_2. The results showed a significant increase in the hydrogen gas generation with the same total cost after increasing the Mg scrap weight from 3.4g to 15g with 50ml amount of HCl.**

Keywords*— hydrogen; hydrolysis; Mg scarp; HCl; Energy cost

I. INTRODUCTION

Since the beginning of the twenty-first century, our dependence on energy sources has increased continuously, therefore there is a need to maintain this energy for the longest possible period of time by rationalizing energy production and consumption. Hydrogen gas is an example of a clean energy carrier; Hydrogen can be used as an alternative source of energy [1]. However, hydrogen can be produced from different renewable and non-renewable (fossil fuel) sources. Hydrogen can be produced by different methods such electrolysis, thermolysis, catalysis, hydrolysis and etc. However, hydrolysis has been attracted the researchers' attention because of the simplicity in production and the high purity of produced H_2 [2].

In addition, some of metals and alloys like aluminium can be used as a potential source to produce H_2 gas by hydrolysis method, which could reduce the cost of hydrogen production [3].

However, sustainable production and supplying of H_2 that can be cost-effective, remains a challenge which invites the efforts of the researchers for the development of a new method/technology. The generation of H_2 by hydrolysis of Mg-based materials (Mg and MgH_2 composites) in the water with different additives such as organic acids, inorganic acids and salts has been studied [4]. However, there are few studies about using Mg scrap as a source of Mg for hydrogen generation via hydrolysis in the presence of HCl [5]. Uan et al. [6] studied the generating of H_2 from magnesium scraps/alloys via hydrolysis using acetic acid as an additive.

In the other hand, nowadays the value of magnesium recycling from mg scraps and wastes has been increased. In addition, Mg scrap can be a potential source for hydrogen generation via hydrolysis. However, the reaction of Mg with water not only leading to H_2 production but also quickly produce $Mg(OH)_2$ which can cover the surface of Mg scraps, produce a passive layer and prevent further reaction. It has been investigated that the liquid acids such as hydrochloric acid (HCl) can prevent the formation of passive layer, accelerate the hydrolysis and consequently hydrogen generation [7].

In this study, Energy cost analysis has been connected for hydrolysis process to calculate the total cost of chemicals that have been used in the process to produce hydrogen. HCl was used to enhance the kinetic of hydrogen generation via hydrolysis using Mg scraps. Hydrolysis is a process that can be controlled by many factors, which directly or indirectly may affect the hydrogen generation. The experimental results showed that the hydrogen generation via hydrolysis using Mg scrap increased by increasing the concentration of HCl. The cost of hydrochloric acid has been estimated with different concentrations to show its effect on hydrogen gas generation depending on the total cost of the process.

In addition, simulation was conducted for the optimum concentration of acid (50%) but with different amount of Mg scrap, to study the cost effectiveness of the process for the hydrogen generation.

II. EXPERIMENTAL PROCEDURE

A. Sample preparation

Mg Scraps were received from Taiwan, which was prepared by Uan and his colleagues [6]. The Mg scraps were cut into smaller sizes which weight was 3.4g and used as hydrogen generation substrate in hydrolysis study following the hydrolysis setup in our earlier study [8].

B. *Energy cost analysis*

The cost of chemicals consumed for the hydrolysis process of the Mg scrap was used to estimate the cost of energy required by the system, also the total cost have been calculated for the required chemicals for hydrolysis if pure Mg is used. Table I illustrate the chemical cost estimated for hydrolysis of Mg scrap. It should be noted that the costs of labour are not quantified in these calculations. The cost of chemical was estimated based on the quantity of consumed raw material for producing of H_2 gas. From Table I, the cost of Mg scrap is not quantified in these calculations, it was assumed to be zero, because it was a part of solid waste produced by industries. Hydrochloric acid which is an additive to prevent passivation and accelerate the hydrogen generation its cost was US$8.25 per 100ml of HCl. Water is not included in cost analysis because its cost is quite minimal in this cost analysis comparing to other chemicals. Water cost should be considered when such calculation is scaled up for industrial purposes.

TABLE I. THE ACTUAL COSTS OF THE RAW MATERIALS HAVE BEEN USED IN HYDROLYSIS USING MG SCRAP.

Material	Unit price	Amount	Unit	Total cost of chemicals ($)
Magnesium scrap (Mg)	0	3.4g	gram	0
Hydrochloric acid (HCl)	Bottle of 100ml (8.25$)	50ml	ml	4.125$
Water (H_2O)	0	50ml	ml	0

The cost of chemical consumed for the hydrolysis process will increase by using pure Mg as the cost of Mg is US$0.12 per gram. A piece of Mg scrap with the weight of 3.4g was used for the same experiment, which costs about $0.3944.

III. RESULTS AND DISCUSSION

A. *Optimization of Hydrogen generation using HCl*

Results of the hydrogen generation by Mg hydrolysis optimization using HCl are summarized in Table II.

TABLE II. *SUMMARY OF THE HYDROLYSIS EXPERIMENTS .*

Curve reference (Fig. 3)	**Sample characteristics**		**Hydrolysis conditions**		**H_2 yield NL(released / theoretical, %)**
	Notation	**Wight (g)**	**Vol. of the solution (ml)**	**Acid Conc. (wt.%)**	***t*=30 min**
$H_2$20	Mg scrap	3.4	10	20	0.37(9.7%)
$H_2$30			0	30	1.2(32%)
$H_2$40				40	1.3(34%)
$H_2$50				50	1.4(37%)

B. *Performance of hydrolysis process depends on energy cost*

The total energy cost has been calculated to show the costs of chemicals that have been used in the hydrolysis process. Figure 3 shows the performance of the hydrolysis for H_2 gas generation depending on the total cost of the processes with different concentrations of HCl.

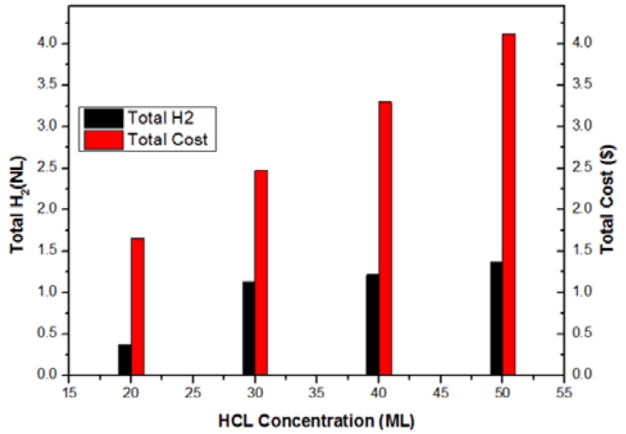

Fig. 1. The total H_2 gas generation with the total cost of the hydrolysis process (the concentration of HCl is the dilution of analytical HCl)

Figure 1 shows that the total energy cost increases while we increase the concentrations of HCl. Depending on our calculation for the used chemicals that have been used; only the hydrochloric acid has been mentioned in the cost analysis. However, a significant increase in the hydrogen gas production have been noted when the concentration of HCl increased from 20 to 50%. Figure 2 shows the performance of hydrogen gas production by increasing the amount of Mg scrap weight using ReaxFF simulation tool.

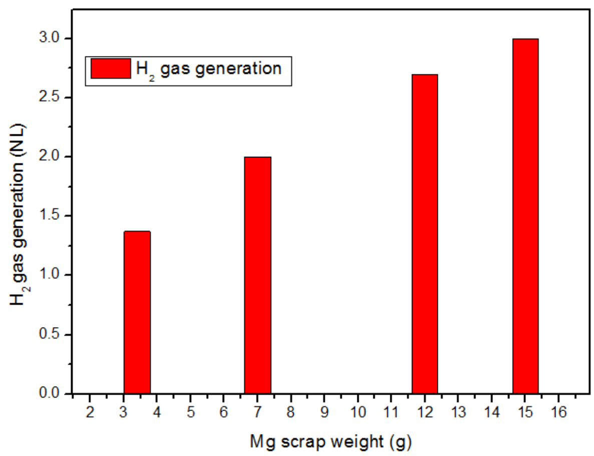

Fig. 2. *Hydrogen gas production with different amount of Mg scraps weight with 50% HCl.*

Depending on the results shown in Figure 2, the hydrogen gas production increased when the Mg scrap weight increased from 3.4g to 15g while the same concentration of HCl (50%) was used. Based on that, larger quantities of hydrogen gas can be produced with the same total energy cost.

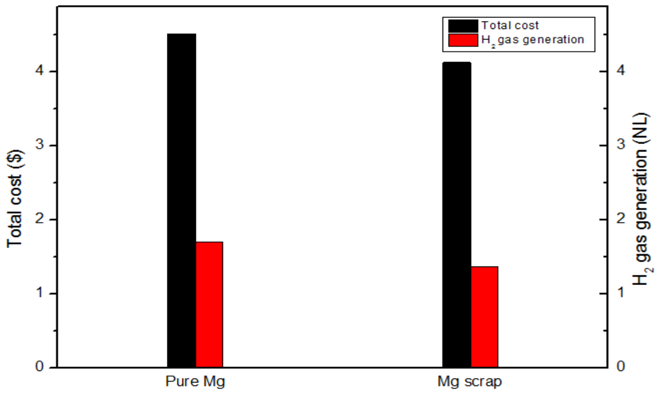

Fig. 3. *A comparison between pure Mg and Mg scrap (hydrogen gas generation and total cost of hydrolysis process).*

To demonstrate the effect of using Mg scrap instead of pure Mg in the total cost, the cost for the hydrolysis process was analysed assuming same amount of pure Mg instead of Mg scrap, which is a solid waste and free of charge. The results have been presented in Figure 3 and as it can be seen for the same amount of Mg in pure Mg produced higher volume of hydrogen comparing to pure Mg while the calculated cost was reduced for Mg scraps. This shows the added value of using Mg scrap as raw material for the hydrogen generation.

IV. Conclusion

Hydrogen generation using Mg scrap via hydrolysis was optimized using different concentration of HCl. Energy cost have been calculated for the materials that have been used in hydrolysis. The results showed a low price process to produce H_2 gas. The benefits of using Mg scrap is to decrease the total cost of the raw used materials. We have elaborated optimization of hydrogen generation using Mg scraps experimentally via hydrolysis to check the values of hydrogen gas generation using different concentrations of HCl (50%, 40%, 30% and 20%). For the 50% HCl solution, the total hydrogen of 37% was released in 5 minutes. The hydrolysis processes was simulated and change in Mg scrap weight showed a significant increase in the hydrogen gas production with the same amount of hydrochloric acid.

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